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# Digital diagnostic complex for power turbine units equipment

**Ilya B Murmanskii\*, Konstantin E Aronson, Vitaly L Blinov, Nikolay V Zhelonkin and Boris E Murmanskyy**

Ural Federal University named after the first President of Russia B.N. Yeltsyn,  
620002 Ekaterinburg, Russia

\* E-mail: i.b.murmansky@urfu.ru

**Abstract.** The study is devoted to the problem formulation for creation a concept of digital complex for power turbine equipment diagnostics using a reference turbine model formed by a set of computational models of thermal and gas-dynamic processes, by diagnostic expert systems (probabilistic type and decision tree type), by functional standard characteristics and statistical models. As part of the study it is proposed to develop diagnostic methods and algorithms for characteristic malfunctions causes for various subsystems of power equipment, which will allow them to be detected at an early stage and to prevent unplanned (emergency) equipment shutdown.

**Key words:** diagnostics, digitalization, power turbines, condition parameters, turbines equipment, reliability, prognostics, expert systems, digital models.

## 1. Introduction

At present research of turbine units' equipment state parameters, their changes forecasting and residual life determining [1–3] have become widespread. In world practice technical condition monitoring and equipment diagnostics are carried out by the Centers operating at the manufacturing plant or large operating organization. At the same time, the working methods of these Centers at the enterprises have been developed individually for many years and are a commercial secret. The manufacturers of steam and gas turbines on the territory of Russia currently do not have such centers [4–5]. Some works of certain enterprises concerning individual areas of diagnosis are known [6–8]. The lack of common approaches to the development of diagnostic tasks for various elements of equipment makes it difficult to implement them at thermal power plants, and the existing complexes of diagnostic tasks cannot be combined into a common system, since they are not connected by a common ideology. In order to combine the tasks of dissimilar equipment diagnosing into a unified system, first of all, the development of a common concept is necessary.

For the formation of common approaches to the development of algorithms for turbine equipment monitoring and diagnosing, it is necessary to take into account the particular qualities of steam and gas turbine units specific equipment in operation. In particular, technical condition estimation for cogeneration, condensing and back pressure turbines is significantly different, both due to variance in the equipment nomenclature and due to different fields of application. Similar problem is noted in the field of gas turbines operation. A wide range of their application (power generation and applied energy, oil and gas and chemical industries, aviation and ship transport, etc.) defines a wide variety of basic unit layouts and their operating conditions, which, respectively, leads to a large number of “individual” features of gas turbine equipment monitoring and diagnostics [9–14]. There are a number of works based on various mathematical models aimed at equipment defects and emergency situations predicting. In particular, the “Prana” system, designed for prediction and remote monitoring, is based on the



mathematical processing of statistical data of technological parameters. At the same time, the effectiveness of this method decreases with an increase in the number of dependent parameters and equipment operating modes. For steam turbines, cogeneration ones in particular, where the collection of statistical data is determined by a large number of operation modes, this approach seems to be imperfect.

In [15] the evaluation of gas turbine state is carried out by argument group accounting method (AGAM). The number of processed parameters for this type of power equipment did not exceed 10 and the evaluation and prediction of defects growth in this case proved to be effective. For steam turbines the number of similar thermo-physical parameters should be significantly (several times) higher due to auxiliary systems in particular. In this regard, such mathematical approaches are rather difficult.

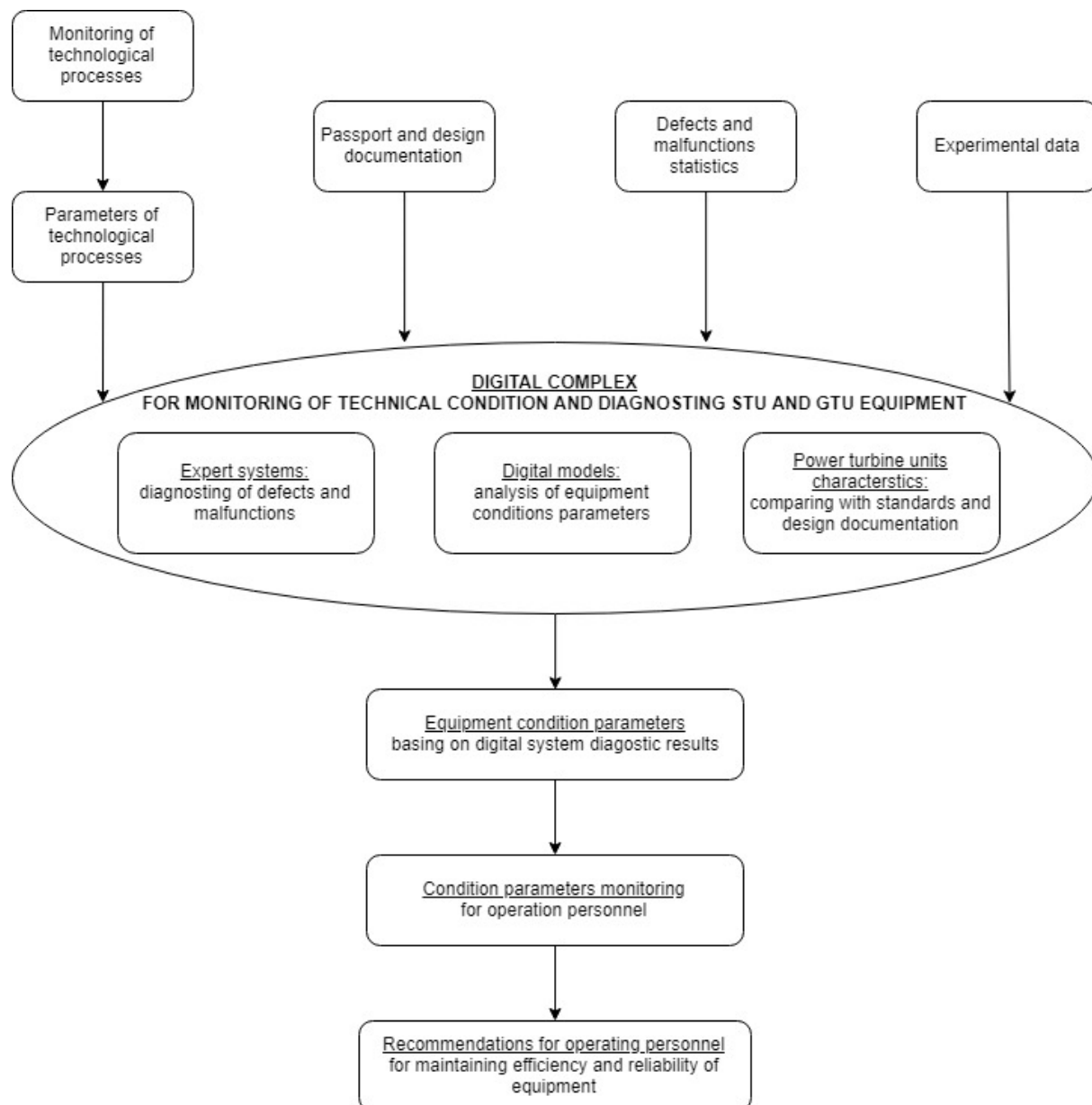
## 2. Concept description

In the framework of this article a concept of digital technologies development for power equipment diagnosing is provided. These digital technologies are aimed at unplanned shutdowns prevention and should lead to a transition to repair strategy based on equipment actual condition. The study is devoted to the problem formulation for creation a concept of digital complex for power turbine equipment diagnostics using a reference turbine model formed by a set of computational models of thermal and gas-dynamic processes, by diagnostic expert systems (of probabilistic type and decision tree type), by functional standard characteristics and statistical models. As a part of the study it is proposed to develop diagnostic methods and algorithms for characteristic malfunctions causes of power equipment various subsystems, which will allow these causes to be detected at an early stage and to prevent unplanned (emergency) equipment shutdown. For system functioning the databases (lists of signals and state parameters obtained by calculation) as well as the knowledge bases (containing damageability indicators and characteristic manifestations of various malfunctions) for steam and gas turbines equipment are developed. Based on the design algorithms of state parameters and on expert systems knowledge bases, certain algorithms for calculating the life of thermally stressed elements of power turbines can be developed, which will allow to proceed to turbine plants repair according to their technical condition (based on the estimated residual life and the service life optimization) and to maintain equipment efficiency and reliability in operation.

Within the framework of the system being developed, various methods for information processing are used to diagnose technical condition parameters:

- an expert systems of probabilistic type and “decision tree” type, which determine equipment defects and malfunctions based on a number of diagnostic signs;
- digital models designed for equipment status parameters calculation and analysis;
- diagnostics based on a comparison of the actual state of the turbine plant equipment with the standard one, determined by the characteristics of normative and technical documentation, regulated by the manufacturer or the industry set-up organization;
- analysis of changes in correlation dependencies between state and mode parameters.

A scheme of the proposed digital complex is shown in Figure 1.



**Figure 1.** The concept of digital diagnostic complex.

The digital complex must have a software in which a number of modules are implemented that correspond to the technological systems of turbine plants. This approach allows for the gradual (step-by-step) implementation of the complex. The following technological subsystems of steam and gas turbine plant as well as fault determination procedures are distinguished for diagnostics, such as: steam turbine flow path (determination of salt drift, of compartments and cylinders efficiency); gas turbine flow path (efficiency determination); axial compressor (drift/pollution, efficiency determination); combustion chamber (evaluation of the gas flow distribution uniformity around the perimeter); steam turbine thermal expansion system (determination of increased friction forces on sliding surfaces, “biting” on a longitudinal key, “biting” on transverse keys); steam turbine vibration state (determination of the blade apparatus defects, of rotor, bearings, couplings defects, etc.); steam turbine condensing unit (determining the degree of condenser surface purity, evaluating the separate effect of air suction and pollution on steam pressure in the condenser, optimal cleaning time, optimal retubing time, ejector diagnosing, determining the efficiency of a circulation pump, etc.); hot water heating system (determination of the purity ratio, optimal cleaning time, optimal retubing time); regenerative feedwater

heating system (determining the causes of main condensate and feedwater temperatures deviations from the standard values by calculating of bypassed water flow rate, pressure loss in the extraction pipe).

Efficiency and output determination of steam and gas turbine as a whole and these parameters degradation monitoring make it possible to assess the overall unit technical condition and its change. The evaluation of turbine unit individual elements and assemblies' efficiency along with other parameters are used to diagnose local causes of changes in their technical state.

The list of defects diagnosed by the system of thermal expansion includes an increased movement resistance on a longitudinal key, increased movement resistance on the sole of the bearing housing, transverse keys "biting" and bearing housing break-off from the base frame.

The list of defects diagnosed on the basis of the vibration state includes scraping along the flow path, rotors thermal deflection, rotors residual deflection, rotor blades breakage, growing cracks in the rotor, babbitt destruction, rotors imbalance, support elements damage, break in half couplings (pendulum), misalignment of the coupling halves, rotor coupling sleeves damage (bolts breakage in rigid couplings).

### 3. Algorithm examples

As the examples of data processing algorithms for various technological subsystems of turbine plant, we consider a number of defects:

- thermal misalignment of steam turbine supports [15,16];
- deviation of the actual vacuum in the condenser from the standard values [17];
- uneven heating of the working fluid in gas turbine combustion chamber.

#### 3.1. Example 1.

The determination of thermal misalignment of steam turbine supports takes place in the Expert System module. The following diagnostic signs of this defect are known in this system: (a) when the vacuum changes in the condenser, the bearing vibration increases; (b) when the generator electric load changes, the bearing vibration increases; (c) babbitt temperature change and others (in this case there are 8 signs of this defect).

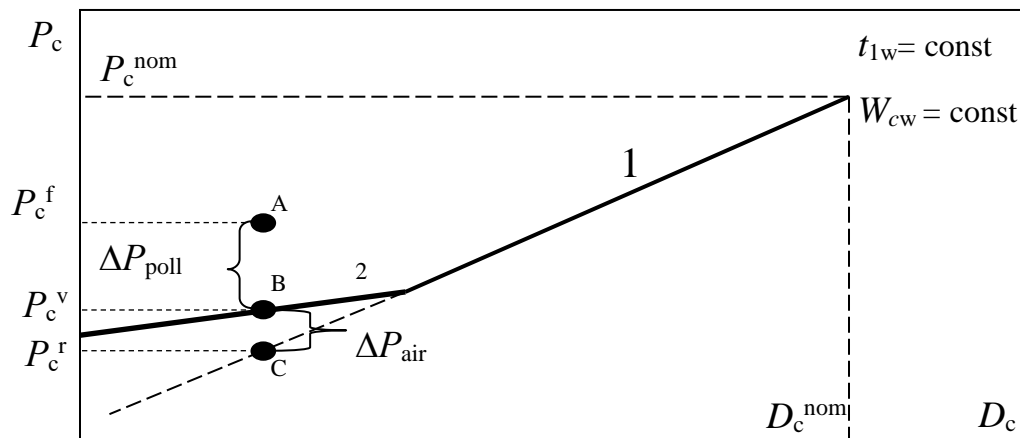
Each sign has a weight fraction to determine the likelihood of a defect occurring when a sign is detected. For each sign a verification algorithm is generated. For example, to detect a change in babbitt temperature the System needs to perform the following:

- determine the temperature of the bearing babbitt at the current time point;
- determine the value of the generator electric load at the current time point;
- find the nearest record in the database in which the value of the generator electric load differs from the current one by 20 %;
- determine the temperature of the bearing babbitt in this record
- compare these two temperatures of the bearing babbitt. If the values differ by more than 5 °C, then the sign is present.

#### 3.2. Example 2.

In the Expert System actual vacuum deviation in the condenser from its standard values is determined by comparing the standard characteristics with the actual values of process parameters.

Figure 2 shows a joint characteristic of a condenser and an ejector, which makes it possible to estimate a pressure change in a condenser due to air suction and tubes fouling.



**Figure 2.** Separate accounting for the effect of air suction and tube fouling on the condenser pressure.

Line 1 is plotted for the standard value of steam pressure in the condenser at fixed inlet water temperature ( $t_{lw}$ ) and water flow rate ( $W_{cw}$ ). Line 2 is a joint characteristic of the condenser and ejector, calculated according to the method described in [6].

Point C in figure 2 determines the calculated value of the steam pressure without taking into account air and pollution ( $P_{cv}$ ); point B is the value of steam pressure in the condenser, taking into account the increased air suction ( $P_{cr}$ ); point A corresponds to the actual value of the steam pressure in the condenser ( $P_{cf}$ ).

Based on the known parameters — circulating water temperature and flow rate, steam flow rate into the condenser and the amount of air removed by the ejectors — the System determines the standard steam pressure in the condenser and compares it with the actual one.

### 3.3. Example 3.

Uneven heating of the working fluid takes place in the combustion chamber of a gas turbine. The uneven temperature field of combustion products at the inlet of the high-pressure part of the gas turbine unit reduces the reliability of the hot section elements and leads to a decrease in their life [18, 19]. Large temperature gradients are the main damage cause of the combustion chamber parts and of the first-stage blade apparatus of the high-pressure turbine. Among the main causes there can be noted thermal barrier coating cracking, warping, fatigue cracking, blades burnout. In addition, in the course of gas turbine unit operation, there are frequent cases of the integrity damage of the diffuser elements — metal deformation, warping of the vanes, cracks and tears, which is associated with high temperatures of the gas turbine exhaust gases (in some cases more than 500 — 600 °C) and with uneven temperature field (temperature distortion) on the exhaust, which can reach hundreds of degrees. Distortion, cracking and rupture of the elements of the gas turbine exhaust diffuser are the result of this uneven temperature, the cause of which, of course, is associated with disturbances in the unit combustion chamber [20]. An increase in the hot gases temperature, along with an increase in the non-uniformity of temperatures around the circumference of the turbines flow part, leads to a decrease in the life of the elements in contact. Thus, a local temperature rise of 50 – 60 °C means an equivalent increase in operating time for the parts washed by this flow approximately by six times, and a design temperature exceeding 100 °C can be equated to a fortyfold increase in the operating time of high temperature parts in this mode [19].

As a rule, several thermocouples are installed at the gas turbine exit around the circumference and along the height of the flow path. Analyzing the actual temperature field in the output section of the gas turbine unit, it is possible to assess the state of the combustion chamber and to determine the sector with “poor technical condition”. Tracking the measured parameters degradation in different modes and comparing them with the available data on the manifestation and development of defects in the elements of the hot path one can build diagnostic signs for their future prediction. As diagnostic criteria there are

used the changes in the total and local differences between the maximum and minimum temperatures of the combustion products (in the circumferential and radial directions along the flow path).

#### 4. Conclusion

The development of digital complexes of this type is widespread in scientific divisions of the world's largest manufacturers of turbine units and among the largest operating organizations. The implementation of the developed digital complex at the energy enterprises of the Russian Federation is an important stage in the introduction of import-substituting technologies that ensure the stability and efficiency of technological processes.

The research results will permit to determine the characteristic defects and propose procedures, models or methods of malfunctions diagnosing for each of the considered technological subsystems of turbine unit. Thus, expert systems are implemented to diagnose the vibration state of the turbine unit, the damages of the condensing unit equipment and of the system of network water heating. Design models are used for assessing the state of the flow path of steam or gas turbine, compressor, of a condensing unit equipment, etc.

It should also be noted that according to the Ministry of Energy the modern electric power complex of Russia includes almost 600 large power plants, of which 68% are thermal power plants. At the same time, it is assumed that the TPP sector will develop in the direction of improving binary technologies, which are fundamental to TPPs around the world. The comprehensive coverage of steam and gas turbines equipment at the first stages of the study makes it possible to further implement the digital complex at binary cycle power plants.

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